

FILLED BOLOMETER ARRAYS FOR HERSCHEL/PACS

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ABSTRACT

Since 1997, CEA/DSM/DAPNIA/ Service d'Astrophysique in Saclay and CEA/DTA/LETI in Grenoble are developing filled Bolometer arrays sensitive in far infrared and submillimeter. These arrays are based on an all Silicon technology development, and are optimized for imaging in high photon background conditions. A 32 x 64 and a 16 x 32 pixels arrays have been developed for the far infrared photometer in the PACS instrument, which is part of the Herschel payload. We present details of the design of these arrays. We describe the performance measurements obtained so far, and give some prospects for future application

INTRODUCTION

HERSCHEL is a far infrared and sub-millimeter observatory to be launched by the European Space Agency in 2007. Its payload includes three instruments; two of them are dedicated to direct imaging and low-resolution spectroscopy. PACS¹, and SPIRE² are designed for observations between 60 and 200 μm , and 200 and 600 μm respectively. Since 1997, CEA/LETI/DOPT/Laboratoire Infrarouge and CEA/DSM/DAPNIA/Service d'Astrophysique are developing new technology bolometer arrays optimized for the Herschel mission. The main driver for the design was the need to provide very good image quality and fast mapping speed in the high background conditions (a few pW/resolution element) that prevails behind the Herschel telescope. These requirements have led to the following constraints:

- Capability to have an optimal sampling of the PSF (0.5 F pixel field of view)
- Large format detector (> 1000 pixels) to get large field of view
- Use of existing technologies to minimize development time and ensure a good production yield
- Integrated cold electronics including cold multiplexer

An additional requirement was the choice of an operating temperature of 300 mK, compatible with ³He sorption cooler, easier to use than dilution coolers that are required for lower temperatures. The noise goal of these detectors is a NEP $\sim 1 \cdot 10^{-16} \text{ W Hz}^{-0.5}$ to achieve BLIP observing conditions in the imaging cameras.

The need for a design based on existing technology has led to an all Silicon design:

- Ionic implantation to obtain resistive thermometers
- Silicon micro-etching to realize suspended absorbing grids
- Flip-chip technology to assemble the different functions
- CMOS cold multiplexer and readout electronics

The first years were devoted to design, tests and optimization of the individual components of the detectors: thermometer, absorbing grids with their metallic layer, grid suspension, and cold electronics. A fully operational detector of 16 x 16 pixels was completed at the end of 1999, which was optimized for the 350 μm channel of

SPIRE. This detector was fully functional, but out of the SPIRE specifications by a factor of 2 in two areas: time constant and noise. The more conventional technology proposed by the JPL/Caltech groups³ was preferred for SPIRE. However, these detectors were compliant with the specifications of the PACS photometer, in which the infrared background is higher than in SPIRE. The PACS photometer was originally designed with stressed Ge:Ga photoconductors, but bolometers provide larger format, and better efficiency than photoconductor arrays. It was decided to modify the PACS design to incorporate our arrays in the instrument. We have upgraded the bolometer array to fit the PACS requirements in terms of wavelength domain and number of pixels. In addition, we have improved our design to decrease their time constant and to make them less sensitive to electromagnetic interferences. We have designed a new mechanical and electrical packaging to ensure a 3 side buttability of individual 16 x 16 arrays to build the large mosaic needed for PACS. The first PACS focal plane was completed in January 2002. Another one has been completed end of March 2002.

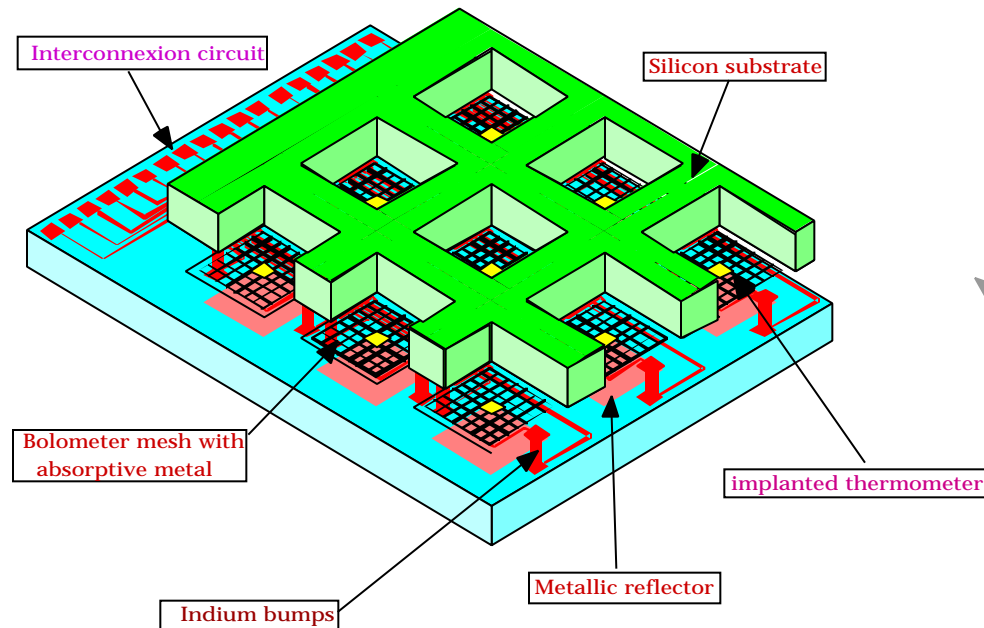


Figure 1: conceptual drawing of the Bolometer array developed for Herschel.

DETECTOR DESIGN

Thermometer

The choice of CMOS cold electronics requires very high impedance thermometers, 1 to 10 G Ω . During the early phases of this project, we have demonstrated that it was possible to achieve such high resistance thermometer with phosphorus implantation and 50% Boron compensation. The realization of these thermometers requires a very accurate control of the ionic implantation parameters. To ensure a good homogeneity of the implantation, we have developed a new process by implantation on a SOI substrate. The thermometer is implanted on the Silicon, above the oxide; then the implantation is homogenized by thermal diffusion. Then contact pads are implanted above the thermometer and micro-etching of the thermometer layer produce the thermometer at the required geometry. Tests have demonstrated that non-ohmic effects are minimum for long linear thermometer. The PACS thermometers have dimensions of 40 μm x 600 μm .

Grids and metallic absorption layer

The absorption principle is based on resonant absorption by a metallic layer placed above a quarter wave resonant cavity. The high absorption efficiency can be extended beyond the vertical resonant cavity peak by suitable grid patterns, which create “horizontal” resonance. Among other patterns, capacitive squares are known to behave as low frequency pass filters, and crosses as band pass filters. In our design, the cavity is created by a gold layer reflector deposited on the Silicon substrate used for the cold readout electronics, indium bumps between the grid support and the electronics Silicon substrate, and a metallic layer deposited on the Silicon grid. To keep the heat capacity of the absorbing layer in a reasonable range, and in particular to avoid its variation with temperature, we use superconductive materials. WN and TiN absorber have been tested with respective thickness of 500 and 380 Å. Both of them are superconductive for DC current, but still keep absorbing properties for frequencies larger than 500 GHz. For the PACS application, TiN is used. Two grid and capacitive loop designs are used, one for each PACS channel. The Silicon structure around the grid is electrically and thermally connected to the readout and multiplexer Silicon plate by indium bump. The height of the indium bump controls the depth of the resonant cavity. 20 and 25 μm bumps are used respectively for the blue and the red channels of PACS.

PACS bolometer pixel design

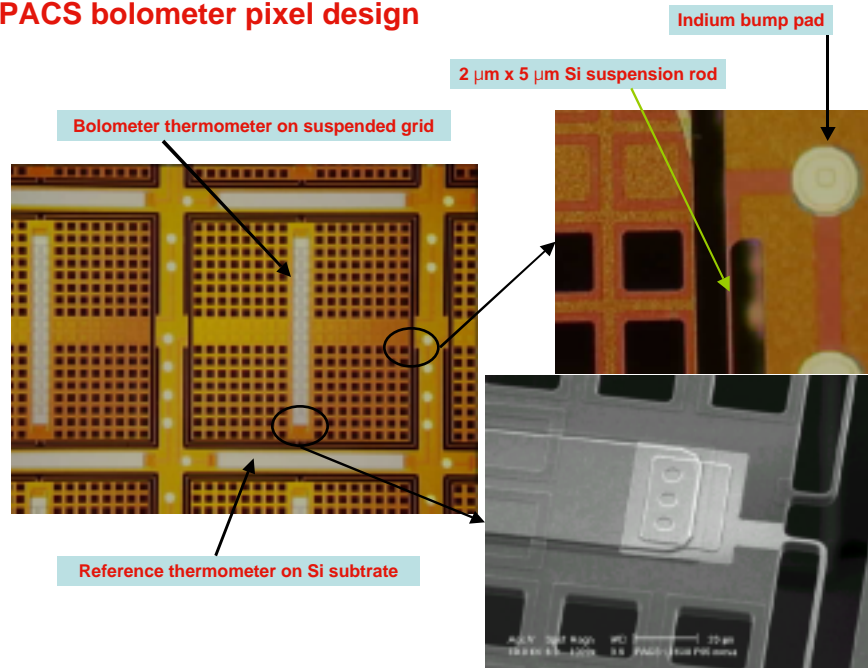


Figure 2: details of the pixel absorbing grid structure.

Thermal design

The thermal decoupling between the grid and the silicon substrate is ensured by thin rods of Silicon. The thermal impedance of these rods is 10^{11} K/W at 0.3 K for rods of 1mm length and $2\mu\text{m} \times 5\mu\text{m}$ section. The thermal impedance for the bulk of the Silicon rod is proportional to T^{-3} , but another component is due to the Si_3N_4 passivation layer, with is proportional to T^{-1} . At 0.3 K, the bulk Silicon dominates the thermal impedance. Despite the superconductive properties of Indium at such low temperature, the thermal conduction through the bump is good enough to keep the structure at the same temperature than the plate. Both of them are thermally connected to the 300 mK cold finger of the cooler through a titanium base plate and a copper strap.

Signal processing

To overcome the intrinsic noise of MOS follower, the Bolometer resistor bridge should be at very high impedance, a few $\text{G}\Omega$. For this reason, the detector is very sensitive to parasitic radio interferences. It also requires very low capacitance lines between the bridge and the first stage of amplification to keep the

BLUE ARRAY CONFIGURATION

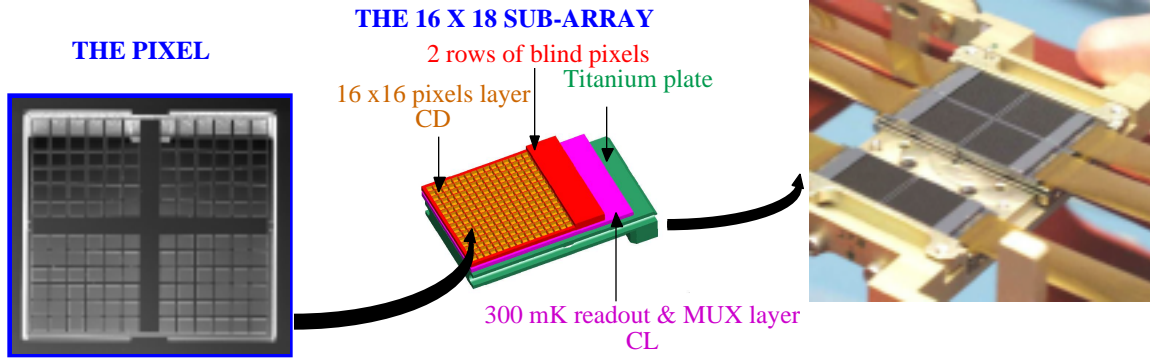


Figure 3: From left to right: a close view of the pixel grid, a schematic drawing of the detector structure, and an intermediate stage of the assembly of the blue PACS focal plane, with only 2x3 arrays of 16x16 pixels each installed on the mosaic support plate.

band pass compatible with the readout frequency, including the multiplexing, namely 3kHz for the PACS bolometers. Another difficulty comes from the slow drift of the DC level of cold MOS transistor, which shows up as 1/f noise in the detector signal. To overcome these difficulties, we have designed a cascade of impedance adaptation levels. The first stage of PMOS follower is implanted directly below the pixel grids, less than a fraction of centimeter from the actual Bolometer resistance. The possibility to communicate between a reference voltage source and the bridge signal allows correlated double sampling to remove the 1/f noise component of the PMOS follower. This stage and the 16 to 1 multiplexer are implanted in the Silicon plate below the absorbing grids. They are all working at 300 mK. A second stage of amplification is provided by a MOS preamplifier at 2 K, connected to the 300 mK stage through a 10 cm ribbon cable. All the preamplifiers required to read two arrays are integrated in a single chip. Then the signal is sent to a JFET amplifier box located on the external side of the cryovessel, at a temperature of 70 K, and then in the warm electronic unit where the signal is digitized and processed.

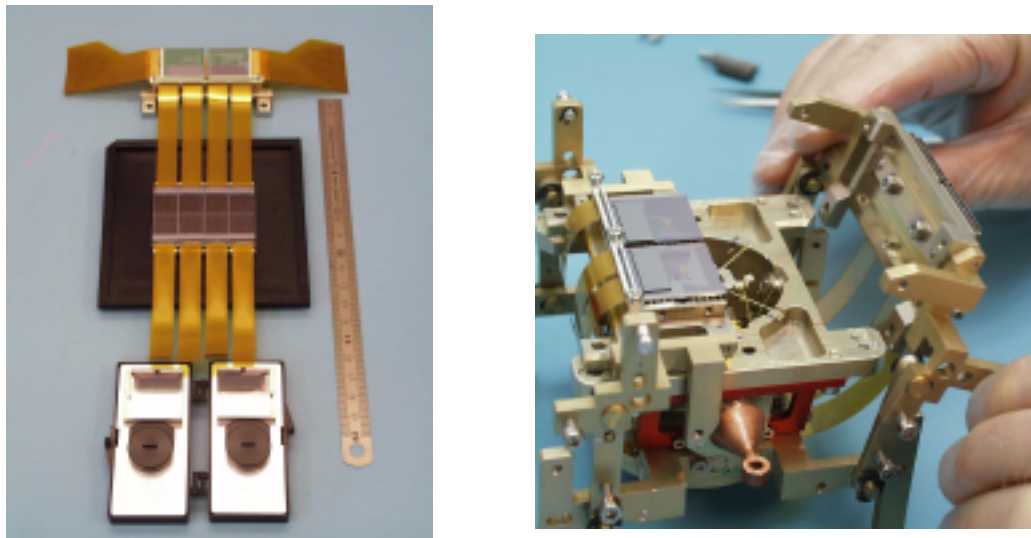


Figure 4: Left image: the blue array of PACS, with the 2x4 arrays of 16x16 pixels each, connected to the 2 K preamplifiers on each side. Each preamplifier chip has 32 outputs, which are used by 2 individual 16 x 16 arrays.. On the right side, the final stage of the detector assembly: the mounting of the preamplifier chips on their common carrier. The 300 mK Kevlar suspended structure is visible on the right of the chips.

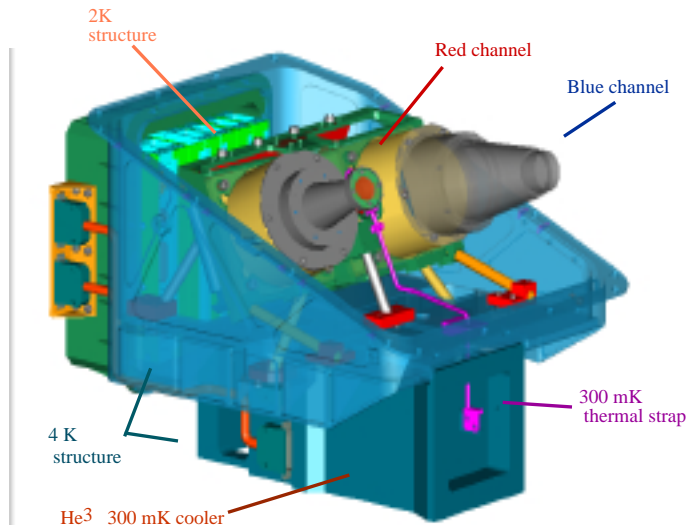


Figure 5 : *The whole PACS focal plane unit*

Two lines of blind pixels are implanted on the side of the 16x16 active pixel arrays. They are used to determine all the collective perturbations to the signal. The 2 K preamplifier makes a differential measurement between active and blind pixels, and sends the differential signal to the 70K and warm stages. A small resistance is implanted on the blind pixels to achieve the same heat load and the same output signal as the active pixels.

(1)

From single array to PACS focal plane

The assembly of the focal plane is a long process, which requires about two weeks. The first step is to manufacture the array mosaic and the electrical connections with the 2K stages with the bonding of all ribbon cables between the 300mK stages and the 2K stages. In a second step, the arrays are installed on the mosaic titanium carrier, which defines the overall geometry. The gap between the arrays in the two directions has been chosen to be 750 μm , which is the pixel pitch. The common carrier is then mounted on a structure suspended to the 2 K level by Kevlar wires. Finally, the ribbon cables between the 300 mK and the 2 K stages are wrapped around the mechanical support and the 2K amplifier chips are screwed on the 2 K titanium carrier common to all these chips. The detector unit is then ready to be mounted in the PACS focal plane housing, which includes the cryocooler, the two channel focal planes, stray light baffles and filters at the 300 mK level

FIRST RESULTS

Mechanical and thermal

The Bolometer arrays have been successfully tested for vibration and shocks at 77 K. The 2 K – 300 mK structure, with dummy bolometers have been vibrated at room temperature. The resonant frequencies are at 200 Hz for the transverse direction, and 500 Hz for the axial direction, well above the 100 Hz specifications. The total suspended mass at 300 mK is 120 g for the blue channel, which is the heavier one.

The heat load from conductance at 300 mK have been estimated to be 1 μW , from conductance measurements done on the Kevlar wires and the ribbon cables alone. The cryocooler power budget for a 48 h cycle is 12 μW . The power budget available for the detector operation is therefore 10 μW , which is compatible with the thermal dissipation of the 300 mK PMOS follower. The overall thermal design has been validated since we have obtained operating temperature as low as 280 mK with a simplified focal plane, and a 2 STP liters cryocooler. The flight cryocooler will be a 6 STP liters.

Optical and electrical

A blue focal plane for PACS was tested in February and March 2002. The test cryostat was not yet fully equipped. In particular, there was no cold chopper, and no filters in front of the cold blackbody used for detector illumination. Nevertheless, we have been able to obtain first results, which demonstrate the functionality of the detectors.

Extensive tests have been performed on the 2 K preamplifier stage alone. Its noise density was measured at 4K to be lower than $0.5 \mu\text{V}/\text{Hz}$ at 2 Hz. The bandwidth with an output capacitance of 1 nF was measured to be 5.5 kHz (needed 3 kHz), for a total power charge on the 2K level of 2.8 mW (3.3 mW max allowed power for 2500 pixels).

All the operating mode of the control and readout electronics, multiplexer, double correlated sampling, differential mode with the blind pixels, have been tested and are functional. The noise measurements were hampered by an error in the grounding inside the cryostat. But the results obtained on the 2 K stage alone with the proper grounding scheme give us confidence that the global noise level will be within the specifications. The infrared background inside the cryostat was a few pW, simulating the thermal load inside the PACS instrument. In these conditions, we measured a response of a few 10^{10} V/W , using a bare 20 K black body. This value is not very accurate since there are no filters in front of the black body, which means that the infrared flux was integrated in the whole detector band.

CONCLUSION AND PROSPECTS

The results obtained so far demonstrate the validity of the technical choices behind the design of these bolometer arrays. The noise performances of the implanted Silicon thermometer and their associated MOS cold electronics should be good enough to achieve BLIP conditions under high background conditions, like in HSO or for direct imagery on ground based telescope. The use of an all Silicon technology is a good choice to manufacture large arrays with a reasonable yield.

Of course, this design will never compete with TES thermometer and SQUID multiplexer to achieve very low noise performances. However, the system design is far more simple with Silicon thermometers and MOS multiplexers: simpler detector manufacturing with Silicon processes, highly integrated cold electronics, 3 side buttability to manufacture large array, and high operating temperature. For all high background applications, where the detector noise is not a real issue, the all Silicon technology is a very serious contender. However, the vacuum resonant cavity achieved by indium bump has a limitation. It can be adapted from 100 μm to 850 μm , but it cannot be extended beyond 1 mm since the high of the indium bumps required to achieve the 1/4 cavity makes them too difficult to manufacture. In a near future, we envisage to develop other arrays at 450 and 800 μm for ground based or balloon instruments. In particular a balloon instrument, ELISA, is under evaluation by CNES, to be launched in 2005 – 2006 (PI: I. Ristorcelli, CESR, France).

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